Model-independent searches for new physics in multi-body invariant masses

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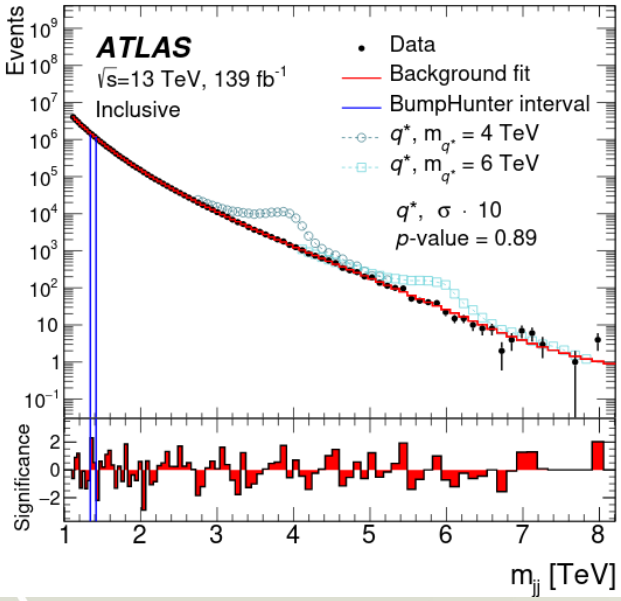
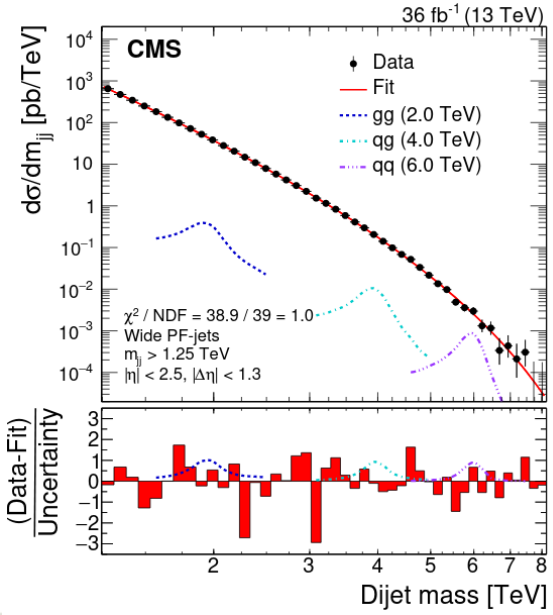
LOI: https://www.snowmass21.org/docs/files/summaries/EF/SNOWMASS21-EF9-TF7-009.pdf

BSM searched in 2-body decays

- **No signs of exotic new physics have yet emerged**
- **Canonical observations of "bumps" in invariant masses focus on 2-body decays (dijets, di-leptons, di-photons etc)**
  - requires very precise knowledge of SM background (~0.1% level)
- **Searches in 2-jets limited by:**
  - Jet triggers → use large invariant masses (mjj>1 TeV)
  - Statistics → use ISR objects to look at medium masses (mjj>250 GeV)
  - MC simulations for bkg. → restrict searches to Γ/M < 0.2 and apply data-driven techniques for background estimates (smoothing, function fits, etc.)





Dijet data are less explored for Mjj<1 TeV and for broad states (for any mass)

← data/bkg < 0.1%

Limitations of LHC & Other opportunities

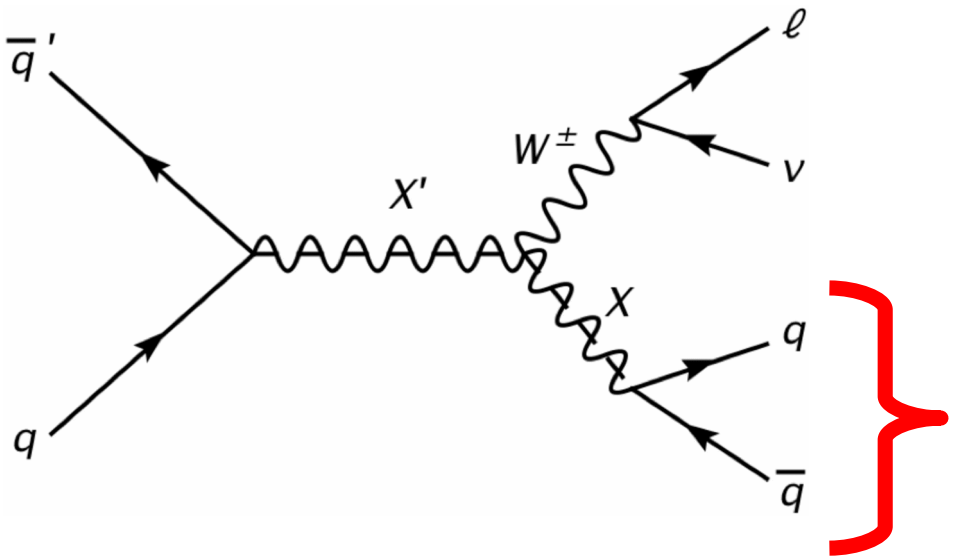
- Limitations for searches in 2-body decays:
  - Low invariant masses m(jj)<1 TeV → Trigger limitation
  - Broad resonances Γ/M > 0.2 (CMS ~0.3) → Monte Carlo limitation etc.

- What if BSM is more complex than we think? → Look at N-body decays closely?
  - ~20 existing publications with 2-jet (gamma, leptons) masses
  - ~4 (only!) publications with 3-body invariant masses

- There is a class of BSM events with cascade decays that cannot easily be found in 2-jet masses (due to large width, low masses etc.), but they still can be probed using 3-body or 4-body decays

- Such class of events can be studied without limitations from:
  - Event trigger (3rd object which can be photon, electron, MET, jets)
  - Monte Carlo for background hypothesis
    - Data control regions are trivially constructed by inverting requirements

Example: s-channel in SSM



Studies are limited to:

Γ(X)/m(X) < 0.2

(or)

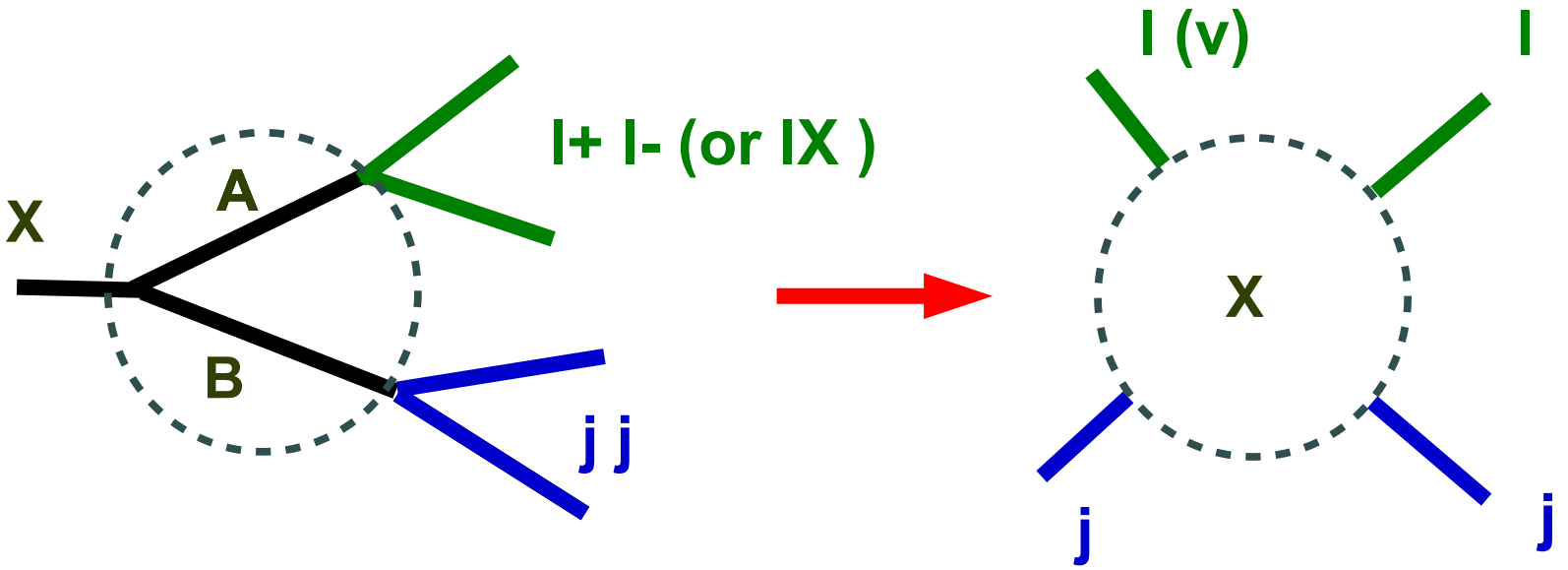
m(X) > 250 GeV

Direct observation of X via 2-body decays can be difficult if:

- broad resonance with Γ/M > 0.2
- low-mass resonances < 250 GeV
- large background for inclusive dijet searches

If X' narrow, this model can be identified via M(jj+l+MET)

General searches : X → A+ B where A and B are unknown



Stay agnostic about the nature of A/B and look at the following invariant masses:

- M(jet jet lepton±)
- M(jet jet jet lepton±)
- M(jet jet lepton+ lepton-)

Possible physics scenario:
2HDM, Graviton models, radion, SSM etc.

If partial width of X is small, peaks in 3- and 4- body invariant masses can be observable even when A/B cannot be observed using 2-body decays due to (1) large width (2) small masses or (3) large background for inclusive searches

Summary & Work plan

- LHC data have not been fully explored in multi-body invariant masses with the same precision as in published papers with 2-body masses
  - "a gold mine" for possible observations

- Experimental searches in multi-body decays can be done without background MC since many control regions can be constructed using data (unlike 2-jet studies)

- **Work plan:**
  - Identify benchmark BSM models which can be probed with this method
  - Focus on **X** → **A+ B** where:
    - **X** is narrow ($\Gamma/M < 0.2$)
    - **A** and **B** decay as 1→2, may not need to be SM particles
  - Create Monte Carlo simulations, study 3- and 4-body invariant masses, and estimate QCD multijet background